A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although portions of this report are not reproducible, it is being made available in microfiche to facilitate the availability of those parts of the document which are legible.

3

LA-UR -87-571

M87006059

CONF-870576--2

TITLE: AN ATMOSPHERIC CORRECTION ALGORITHM FOR REMOTE IDENTIFICATION OF NON-LAMBERTIAN SURFACES AND ITS RANGE OF VALIDITY

LA-UR--87-571

DE87 006059

AUTHOR(S): ANNEGRET GRATZKI, T-DOT
S.A.W. GERSTL, T-DOT

SUBMITTED TO: FOR PRESENTATION AT THE IGARSS '87 MEETING TO BE HELD AT THE UNIVERSITY OF MICHIGAN, ANN ARBOR, MICHIGAN, MAY 18-21, 1987

FEBRUARY 20, 1987

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

AN ATMOSPHERIC CORRECTION ALGORITHM FOR REMOTE IDENTIFICATION OF NON-LAMBERTIAN SURFACES AND ITS RANGE OF VALIDITY

Annegret Gratzki and S.A.W. Gerstl

Los Alamos National Laboratory
Theoretical Division, MS-P371
Los Alamos, NM 87545

Abstract

The usefulness of remotely sensed surface data depends on the ability to correct for atmospheric pertubations on the image. An atmospheric correction algorithm has been proposed by Gerstl and Simmer (Ref.1) which removes atmospheric pertubations from off-nadir measured radiances at the top of the atmosphere in the visible and near-infrared wavelength region. The ability of the model to reproduce radiance distributions at the surface from radiances at the top of the atmosphere is tested and found to be better then 15%. The correction formalism requires as minimum information the total optical depth of the atmosphere and the surface albedo. In this study the accuracy of the model to assumptions about the aerosol phase function, the single-scattering albedo and the vertical profile of the optical depth is also tested.

1. Introduction

Signals received by radiometers aboard aircraft or satellites in the visible or near-infrared wavelength region contain information about the Earth's surface and the atmosphere. In the case of surface remote sensing, the atmospheric signal is undesirable because it tends to blurr the data and therefore makes surface identification more difficult (Ref.2) . These atmospheric effects depend on many parameters including surface reflectance characteristics, aerosol and gaseous optical characteristics, clouds, solar zenith angle and direction of observation if off-nadir sensors are considerd. Since off-nadir remote sensing provides important information about vegetative surfaces (Ref.3), it is desirable to have an atmospheric correction algorithm usable for off-nadir look angles. Such an atmospheric correction algorithm has recently been proposed by Gerstl and Simmer (Ref.1) . The algorithm retrieves the angular distribution of the reflected radiance directly above a non-Lambertian surface from radiance measurements at the top of the atmosphere . This algorithm is tested and its range of applicability determined.

2. Model Description

The signal received by a radiometer aboard an aircraft or satellite consists of three components:

(1) radiation from the viewed surface, modified by the atmosphere

(2) radiation that does not reach the surface and comes to the sensor through atmospheric scattering

(3) radiation from surrounding surfaces outside the instantaneous field of view of the sensor ("adjacency effect", see Ref.4).

Components (2) and (3) contain no information about the investigated surface and have to be removed from the signal, whereas only (1) contains the desired information. In the following study we neglect the contribution from (3) and limit ourselves to one-dimensional calculations. The correction algorithm tested is based upon the fact that for low optical depth the atmospheric effects on the surface are mainly additive (Ref.1) and therefore can be subtracted from the reflectance data at the top of the atmosphere to derive the reflectance distribution at the surface. To calculate the atmospheric effect, the minimum information required is the total optical depth τ of the atmosphere and the surface albedo α . The correction algorithm has the following form:

$$R_{derived}(z=0,\vec{\Omega}) = R(z_{TOP},\vec{\Omega}) - \left[R^{\alpha,\tau}_{LAMB}(z_{TOP},\vec{\Omega}) - R_{LAMB}(z=0,\vec{\Omega})\right]$$

$$= R(z_{TOP},\vec{\Omega}) - R^{ATMOS}_{LAMB}(\vec{\Omega}) \qquad (1)$$

The symbol R stands for the normalized radiance distribution function as defired in Ref.1 and is called "reflectance" for brevity.

$R(z=0,\vec{\Omega})$: derived reflectance at the surface

$R(z_{top},\vec{\Omega})$: simulated measured reflectance at the top of the atmosphere

$R^{atmos}_{LAMB}(\vec{\Omega})$: calculated atmospheric effect

$R^{\alpha,\tau}_{LAMB}(z_{top},\vec{\Omega})$: calculated reflectance at the top of the atmosphere with an optical thickness τ above a Lambertian surface with albedo α

$R^{\alpha,\tau}_{LAMB}(z=0,\vec{\Omega})$: calculated reflectance above the Lambertian surface with albedo α.

$R^{\alpha,\tau}_{LAMB}(z_{top},\vec{\Omega})$ and $R^{\alpha,\tau}_{LAMB}(z=0,\vec{\Omega})$ are calculated by solving the radiative transfer equation in plane-parallel slab geometry with the computer code ONEDANT which is described in Ref.5. In addition to the total optical depth the atmosphere can be characterized by the vertical profiles of the optical depth, phase function and single scattering albedo , if available. If this information is not available and the algorithm is applied to actual satellite data, assumptions about these parameters must be made.
Paragraph 3 studies the accuracy of the model under complete knowledge of the atmospheric radiation parameters and paragraph 4 investigates the sensitivity of the model to assumptions of those parameters.

3. Model Accuracy

Calculations were made with a five layer model atmosphere, representing a midlatitude summer atmosphere, with a rural aerosol and 23 km surface visual range in the boundary layer. The aerosol phase function is approximated by the Henyey-Greenstein function which is only a function of the asymmetry parameter g. Our computational model uses 144 discrete directions in each hemisphere and a phase function expansion of 17 Legendre moments. To simulate measurements made at the top of the atmosphere, transport calculations are made with a measured bidirectional reflectance distribution function (BRDF) representing coniferous forest and savannah (Ref.6) in the visible spectral region (λ=0.65 μm) and near-infrared wavelength region (λ=0.85μm) for four solar zenith angles (= 8°, 20°, 45°, 60°). The reflectance at the surface ("ground truth") was also derived from the calculations. The correction was made with the same atmospheric parameters, but Lambertian surface with the albedo of coniferous forest at λ =0.65μm and λ =0.85μm (α=0.015 and 0.097) and the albedo of savannah for λ=0.65μm (α=0.093). In the visible reflectances at the surface can be reproduced with an error of less then 15% for coniferous forest and less then 10% for savannah with view zenith angles and solar zenith angles smaller then 60°. For λ =0.85μm the error is less then 8% for zenith angles smaller than 60°.

4. Model Sensitivity

If the total optical depth of the atmosphere is known, assumptions have to be made about the vertical profiles of:
- phase function as expressed by the asymmetry parameter g(z)
- single scattering albedo $\tilde{\omega}$ (z)
- optical depth τ (z)

To study the sensitivity of the model to these assumptions, calculations were made with variations of g(z), $\tilde{\omega}$ (z) and τ (z) to one reference case (Fig.1) that is choosen as
- λ =0.65 μm
- midlatitude summer atmosphere
- rural aerosol in the boundary layer (1 to 2km) with a surface visual range of 23 km
- solar zenith angle 20°
- measured BRDF of coniferous forest.

The vertical profiles of g, $\tilde{\omega}$ and τ for the reference model are shown in table 1. To perform the sensitivity study, only one of the three parameters was varied and all others kept constant in the following way:
- set g to a constant value in all layers
- change of τ in the boundary layer and troposphere, keeping the total optical depth constant
- set $\tilde{\omega}$ to 1.0 in all layers.

To study the influence of the vertical profile of τ , leaving the total optical thickness constant, τ was increased in the boundary layer and correspondingly decreased in the troposphere and vice versa.

$$\Delta\tau_{TROP} = -\Delta\tau_{BL} \qquad (2)$$

Only the aerosol optical thickness was changed since this is the most variable parameter. There were no changes made in the optical depth of the upper atmosphere since this influence is negligible. As can be seen from Fig.2 the flux

$$\int_{\phi=0}^{360} d\phi \int_{\theta=0}^{90} L(\theta,\phi)\cos\theta \sin\theta \, d\theta \qquad (3)$$

(L is the radiance) at the top of the atmosphere is significantly influenced when $\Delta\tau_{BL}$ is positiv or negativ. If $\Delta\tau_{BL}$ is negativ, the total downward flux at the surface is reduced, and therefore the amount of energy absorbed by the surface is smaller than if $\Delta\tau_{BL}$ is positive. But the error

$$RD = \frac{R_{derived}(z=0,\vec{\Omega}) - R_{simulated}(z=0,\vec{\Omega})}{R_{simulated}(z=0,\vec{\Omega})} \qquad (4)$$

induced by reducing or increasing τ in the boundary layer (Fig.3) by the same amount is not equal. The reason is that in increasing the optical depth in the boundary layer, there is enhanced scattering between the surface and the atmosphere, and therefore the total amount of energy absorbed at the surface is higher than in the case of reducing τ in the boundary layer by the same amount. So by increasing the optical depth in the boundary layer by an amount $+\Delta\tau_{BL}$, the calculated atmospheric effect is changed by a factor, which is not the same as in the case of reducing the optical depth in the boundary layer by the same amount. The reflectances are two to three times more sensitiv to $+\Delta\tau_{BL}$ than to $+\Delta\tau_{TR}$ for $\tau \leq 0.08$.

Calculations were made changing g in every layer to 0.0, 0.2, 0.4,0.6 and 0.7. The choice of g (Fig.4 and 5) has significant influence on the downward flux reaching the surface and the upward flux at the top of the atmosphere. Since the albedo of the surface is very low (A=0.015), the upward flux from the surface is not very much influenced by the choice of g. The accuracy of the derived reflectances at the surface (Eq.1) is mainly influenced by the upward flux at the top of the atmosphere, which shows values more than two times higher than the reference case. The reason for this difference is that in reducing the forward scattering peak and moving towards a more isotropic phase function ($g \to 0$), less radiation reaches the surface and more radiation is directly scattered back to the top of the atmosphere. That means, if all the other parameters are known, g has to be determined very accurately to estimate the atmospheric effect correctly. As our calculations show, a value of g=0.7, which represents a difference of 3% to the reference g in the boundary layer and 10% in the troposphere, still produces errors up to 16% for the surface reflectance for θ_{view} 60°.

To study the influence of g on the angular distribution of the surface radiation field, $R^{\downarrow,T}_{Lamb}(z=0,\vec{\Omega})$ and $R^{\uparrow,T}_{Lamb}(z_{TOP},\vec{\Omega})$ were normalized so that the fluxes at the surface and at the top of the atmosphere equal the respective fluxes $R^{\downarrow,T}_{Lamb}(z=0,\vec{\Omega})$ and $R^{\uparrow,T}_{Lamb}(z_{TOP},\vec{\Omega})$ calculated with the atmospheric parameters in the reference case. The influence of g on the angular distribution is shown in Fig.6, where the relative difference, as defined in Eq. 4, is plotted against the view zenith angle and averaged over all view azimuth angles. The choice of g has significant influence on the angular distribution, especially for $\theta_{view} \leq 10°$. As one would expect, the error does not increase with decreasing g. The reason can be seen from Fig.7, which shows how the energy for a specific g is distributed depending on the zenith angle. Depending on the form of the forward scattering peak, more or less energy is distributed to lower zenith angles, which in turn affects the accuracy of the calculated atmospheric effect.

Since $\tilde{\omega}$ is very high in the visible for the lower elevations of the atmosphere, the error (RD) induced by assuming $\tilde{\omega}$ =1 is smaller then 1% for θ_{view}=0° and increses to 15% for θ_{view} =60°.

5. Conclusions

For low optical depth $\tau \leq 0.04$ the model can reproduce the radiance distribution at the surface with better than 15% accuracy for all view zenith angles and solar zenith angles smaller than 60°. The phase function, or the asymmetry parameter g, has to be known very accurately ($\Delta g \leq 10\%$) to determine the total amount of energy and to obtain the correct angular representation. For atmospheres with low optical depth, the algorithm gives better results when the optical depth in the boundary layer is underestimated at the cost of overestimating the optical depth in the troposphere.

References:

(1) Gerstl, S.A.W. and C. Simmer, Rem. Sens. Envir., 20, 1-29, 1986.

(2) Slater, P.N.,1980: Optics and Optical Systems, Addison-Wesley, Reading.

(3) Simmer, C. and S.A.W. Gerstl, IEEE Trans. Geosci. Remote Sens. GE-23, no. 5, 648-658, 1985.

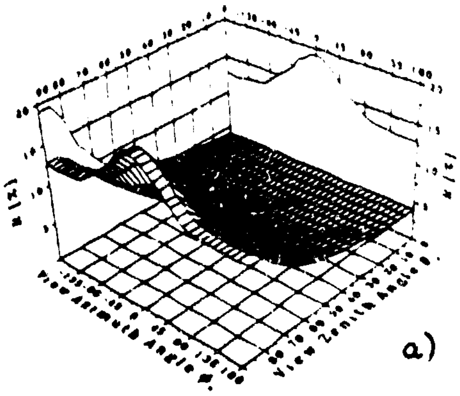
(4) Otterman, J. and R.S. Fraser, Appl. Opt., vol. 18, no. 16, 2852-2860, 1978.

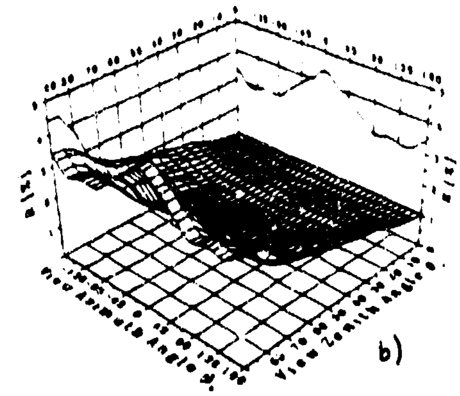
(5) Gerstl, S.A.W. and A. Zardecki, Appl. Opt., vol. 24, no. 1, 81-97, 1985.

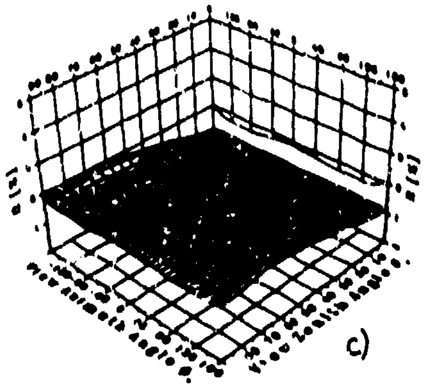
(6) Friebel, F.T., Muenchener Universitaetsschriften, Meteorologisches Institut, Wissenschaftliche Mitteilung Nr. 29,1977.

	τ	$\tilde{\omega}$	g	
layer 1 (0-2 km)	0.01	0.97	0.72	BOUNDARY LAYER
layer 2 (1-2km)	0.07	0.97	0.72	BOUNDARY LAYER
layer 3 (2-9km)	0.11	0.95	0.62	TROPOSPHSPE
layer 4 (9-30km)	0.03	0.61	0.70	STRATOSPHERE
layer 5 (30-70 km)	0.0043	0.18	0.74	UPPER ATMOSPHERE

Table 1: Vertical profile of the optical depth τ, the single scattering albedo $\tilde{\omega}$ and the asymmetry parameter g for the reference case.







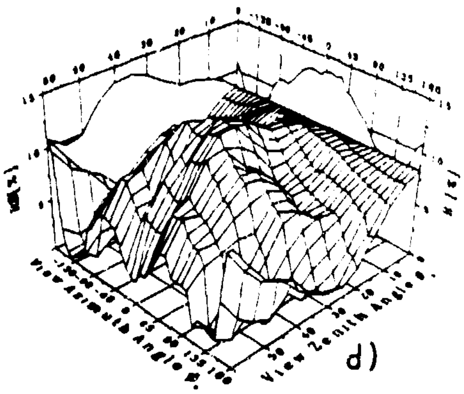


Fig. 1: a) simulated measured reflectance distribution at the top of the atmosphere
b) simulated reflectance distribution ("ground truth") above a coniferous forest
c) derived reflectance distribution above coniferous forest, calculated with the atm. correction formalism
d) relative difference (RD) between the simulated and derived reflectances at the surface in percent

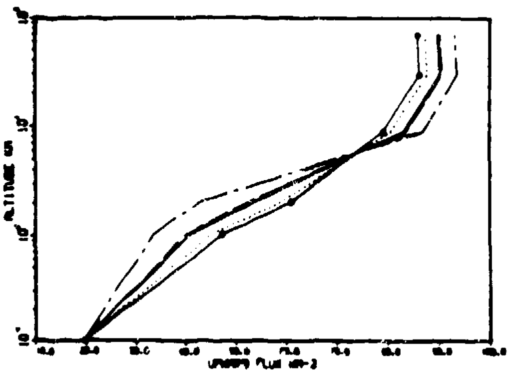


Fig.2 : Upward flux at each model layer reference atmosphere, Lambertian surface, albedo=0.015
Δ3L =-0.01
Δ3L =-0.05
Δ3L =+0.05
Δ3L =-0.08
Δ3L =+0.08

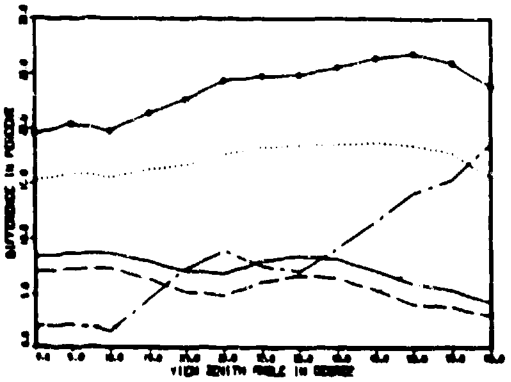


Fig. 3: Relative difference in percent between the erived radiances and the simulated radiances, RD, averaged over all azimuth angles.
For definition of curves see Fig. 2.

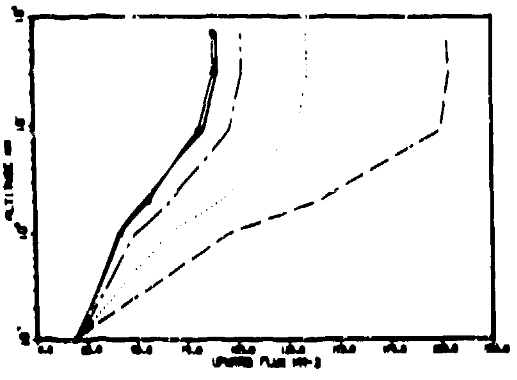


Fig. 4: Upward flux at each model layer reference atm., Lamb. surface albedo=0.015
g=0.0
g=0.2
g=0.4
g=0.6
g=0.7

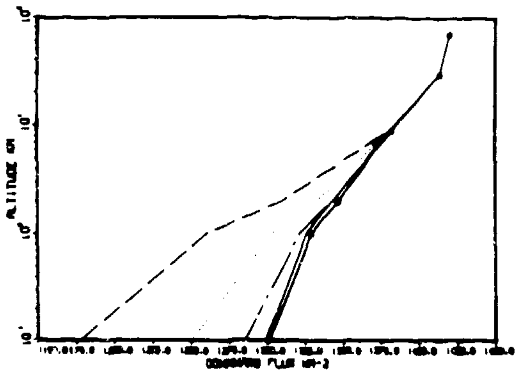


Fig. 5: As Fig. 4 for the downward flux

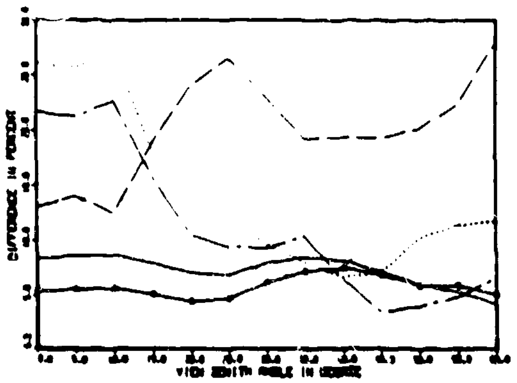


Fig. 6: Relativ difference in percent between derived and simulated radiances, RD, averaged over all azimuth angles.
For definition of curves see Fig. 4.

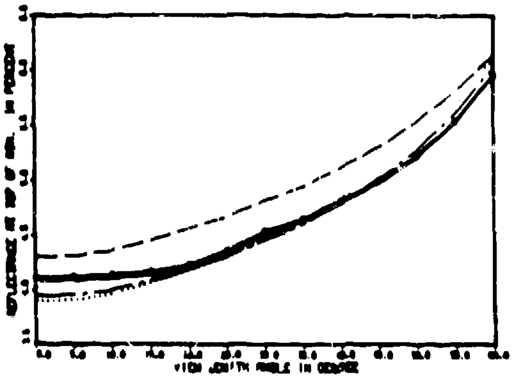


Fig. 7: Reflectance at the top of the atmosphere, averaged over all azimuth angles in percent. For definition of curves see Fig. 4.